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(56) Documents Cited
GB 2311829 A
GB 2308874 A
EP 0990819 A1
EP 0514829 A2
US 6050155 A
US 4044274 A

(58) Field of Search
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INT CL[7] B25J 9/10, F16H 49/00 55/08 61/32 61/34 63/16 63/18
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(54) Abstract Title
**An electric motor gear actuator with harmonic drive**

(57) An electric motor actuator, for control of a gear selector mechanism, has a drive ratio of from -40:1 to -60:1 and comprises an electric motor 16 mounted coaxially inside a shift drum 40 driven by a harmonic drive. The harmonic drive comprises an elliptical wave generator 12 mounted on the rotor 14 and a flexible cup shaped spline gear 20 connected, eg by bolts, to the shift drum 40. Flexible spline gear 20 has fewer splines than an annular spline gear 24 and the wave generator 12 being of elliptical shape causes the splines of the flexible spline gear 20 only to mesh with the splines of the annular spline gear 24 at angularly spaced diametrically opposed locations. The shift drum 40 is supported by bearings 46 on a mounting member 32 which is fixed to a support member (208, fig 4). In another embodiment two electric motor shift drum assemblies are mounted coaxially on a shaft to form a double shift drum actuator (see fig 4).

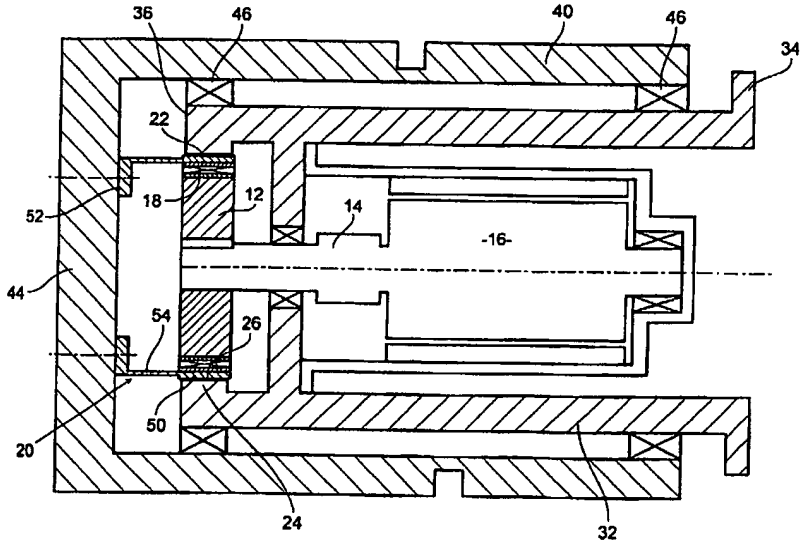


Fig 3.

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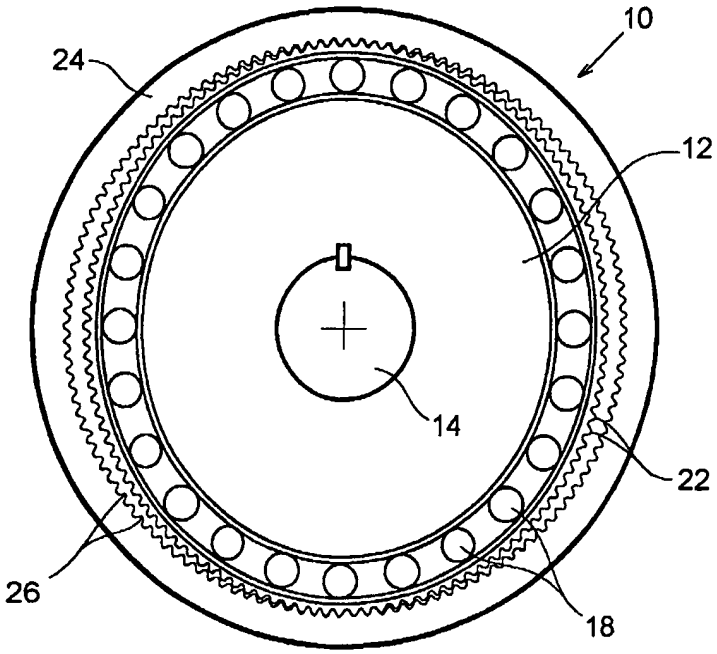


Fig 1.

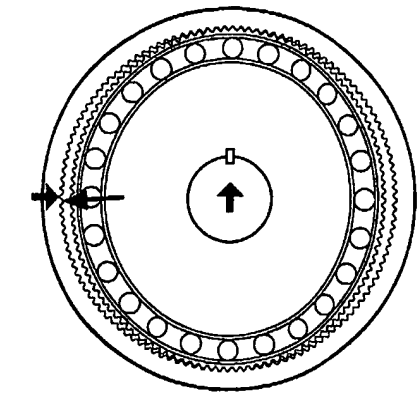

Fig 2b.

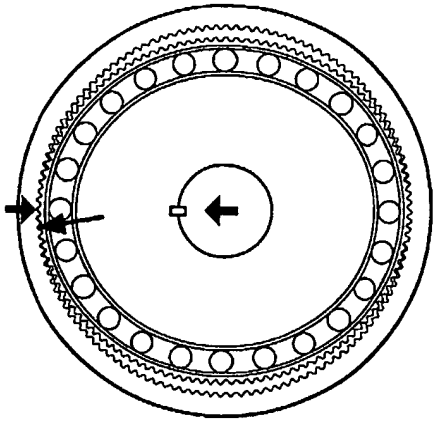

Fig 2d.

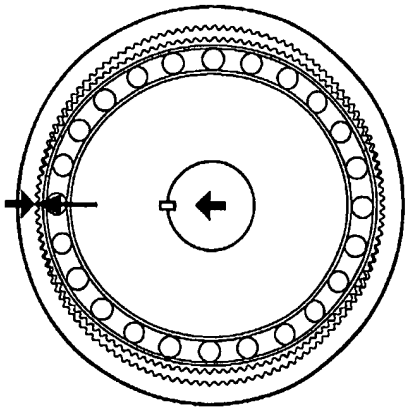

Fig 2a.

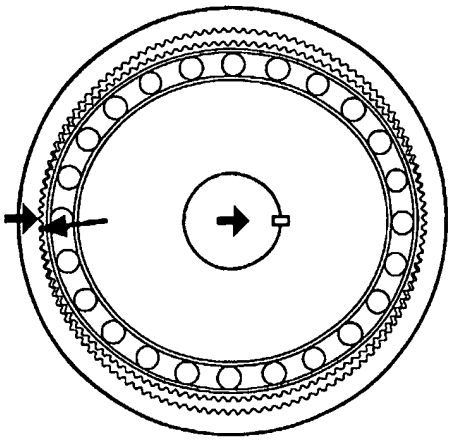

Fig 2c.

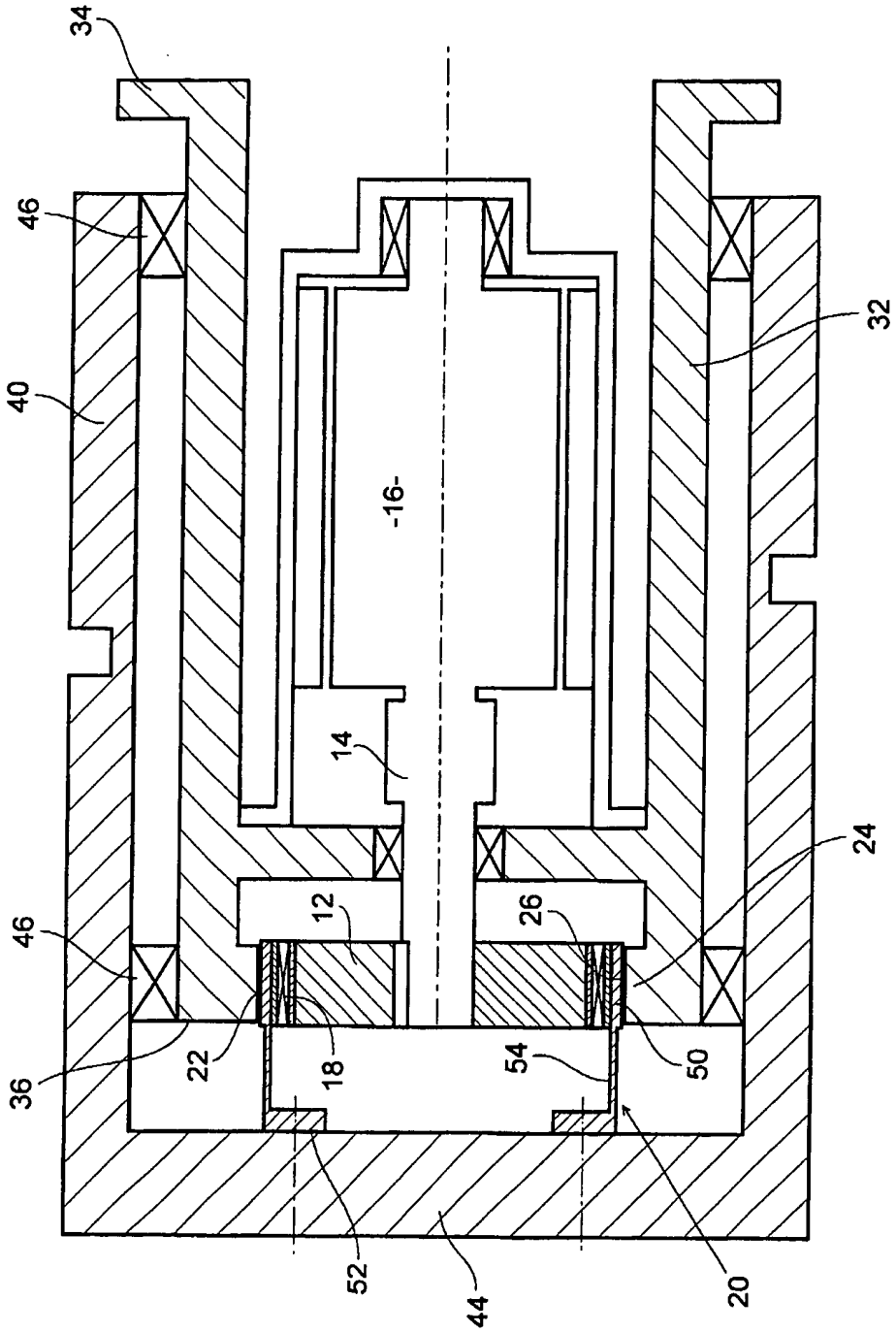


Fig 3.

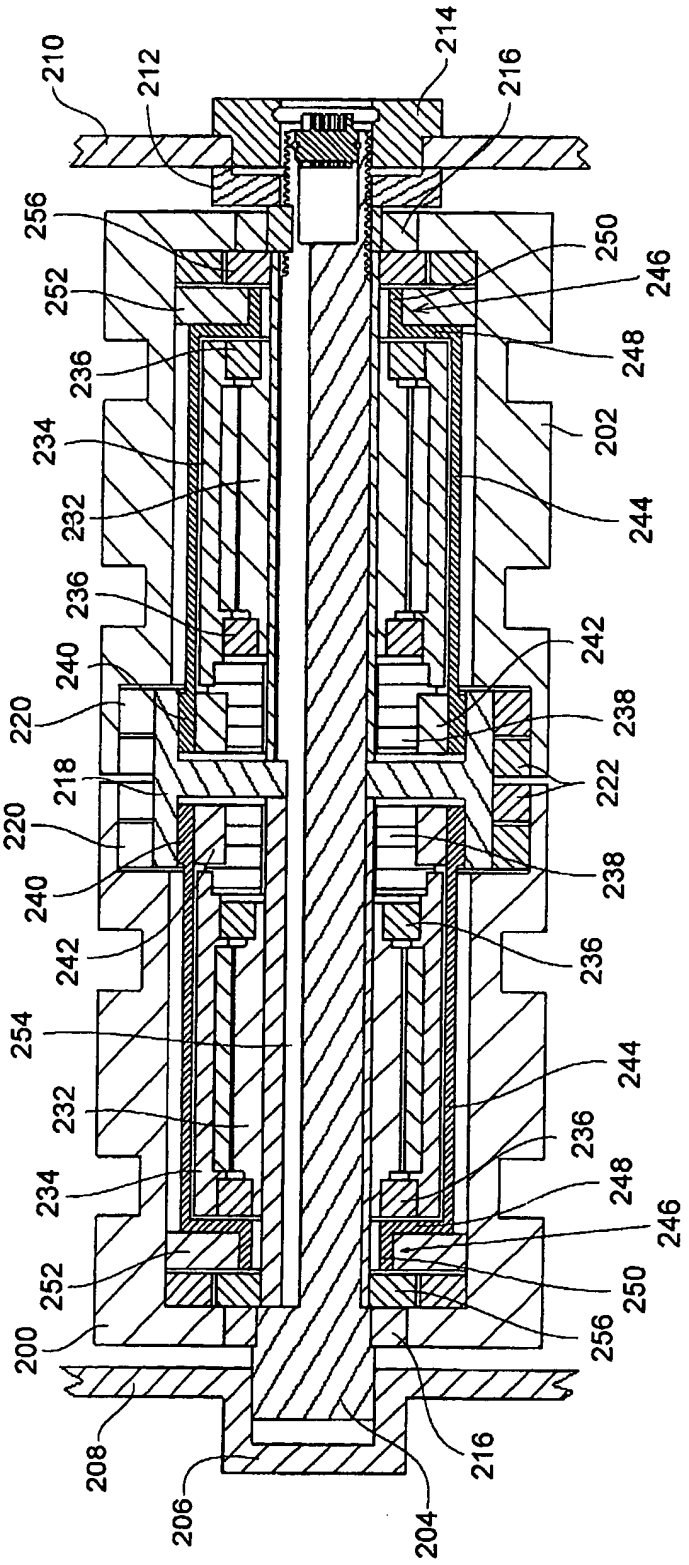
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Fig 4.

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**Gear Actuators**

The present invention relates to gear actuators and in particular electric motor actuators for control of a gear selector mechanism of an automated transmission systems of a motor vehicle.

Electric motor actuators which are used to control the gear shifter mechanisms of automated transmission systems typically utilise a worm and worm gear drive mechanism to provide a high ratio reduction, for example as disclosed in GB2325036, GB2313885 and GB2309761 the disclosure of which explicit reference is made and whose content is expressly incorporated in the disclosure content of the present application, in order to convert the high speed, relatively low torque drive of the electric motor into a slow speed relatively high torque required to actuate a gear shifter mechanism. Typically the drive ratios of such mechanisms are of the order of 40:1 to 60:1.

The worm gear drives utilised hitherto have the disadvantage that they are relatively large and present serious difficulties with regard to the packaging constraints encountered in automated transmission systems for motor vehicles.

Moreover use of such electric motor actuators with shift drums, for example as disclosed in GB2308874 and GB2311829 the disclosures of which explicit reference is made and whose content is expressly incorporated in the disclosure content of the present application, present particular difficulties in this respect.

The present invention utilises a high ratio drive of concentric construction with a shift drum to provide a compact electric motor gear selector actuator.

In accordance with one aspect of the present invention an electric motor actuator for control of a gear selector mechanism of a motor vehicle; includes a mounting member by which the actuator may be mounted with respect to a support member, a shift drum mounted for rotation relative to the mounting member, an electric motor mounted coaxially inside the shift drum, the electric motor having a stator mounted non-rotatably with respect to the mounting member and a rotor, the rotor being drivingly connected to the shift drum for rotation thereof by means of a harmonic drive, the harmonic drive comprising a wave generator mounted on the rotor for rotation therewith, an annular spline gear non-rotatably mounted with respect to the mounting member concentrically of the wave generator and a flexible spline gear located between the wave generator and the annular spline gear, the flexible spline gear being drivingly connected to the shift drum, the flexible spline gear having fewer splines than the annular spline gear and the wave generator being shaped to cause the splines of the flexible spline gear to mesh with the splines of the annular spline gear at angularly spaced locations, the splines of the flexible spline gear being clear of the splines of the annular spline gear, intermediate of said locations.

In the actuator described above the electric motor and harmonic drive mechanism are located coaxially within the shift drum, thereby providing a compact actuator. The drive ratio of the harmonic drive will depend on the difference in the number of splines between the annular spline gear and flexible spline gear:-

ie. the drive ratio $i = \frac{-n}{N}$

Where; $n$ = the difference in the number of splines between the annular spline gear and the flexible spline gear;

$N$ = the number of splines on the flexible spline gear;

the negative value denotes that rotation of the shift drum is in the opposite direction to the direction of rotation of the rotor.

Preferably the drive ratio is of the order of -40:1 to -60:1. In a typical example, the annular spline gear will have 102 splines and the flexible spline gear 100 splines, giving a drive ratio of -50:1.

According to one embodiment of the invention the electric motor shift drum actuators of the present invention are formed individually, so that they may be secured, for example, to a gearbox housing, in suitable position to actuate the gear selector mechanism. However, particularly for use with twin clutch transmission systems of the type disclosed in co-pending UK Patent Applications GB 0028310 and GB 0103312 the disclosures of which explicit reference is made and whose content is expressly incorporated in the disclosure content of the present application, it is advantageous to provide double shift drum actuators. Furthermore the shift drum actuators of the present invention may advantageously be located within a gearbox housing of a motor vehicle.

The invention is now described by way of example only, with reference to the accompany drawings, in which:

Figure 1 illustrates diagramatically in cross section a harmonic drive mechanism of the type used in the electric motor gear actuators of the present invention;

Figure 2 illustrates diagramatically the relative positions of the components of the harmonic drive, during one rotation;

Figure 3 shows in sectional side elevation a shift drum actuator in accordance with the present invention; and

Figure 4 shows in sectional side elevation a double shift drum actuator in accordance with the present invention.

As illustrated in figure 1 a harmonic drive 10 as used in the electric motor actuator of the present invention comprises a wave generator 12 mounted on an output shaft 14 of an electric motor, the wave generator being keyed to the shaft 14, for rotation therewith. The wave generator 12 is of elliptical configuration with a thin flexible raced rolling bearing 18 fitted to the outer periphery thereof.

A flexible spline gear 20 is mounted on the outer race of the rolling bearing 18, the flexible spline gear 20 comprising a thin flexible endless band with axially extending splines 22 on its outer surface.

An annular spline gear 24 is non-rotatably mounted concentrically of the wave generator 12/flexible spline gear 20 assembly. The annular spline gear 24 has a series of axially extending splines 26 on its inner periphery. The annular spline gear 24 has an internal diameter equal to the major axis of the elliptical wave generator 12/rolling bearing 18/flexible spline gear 20 assembly, so that the splines 22 of the flexible spline gear 20 mesh with splines 26 of the annular spline gear 24 at diametrically opposed positions, on the major axis of the wave generator 12.

The minor axis of the wave generator 12 is such that the splines 22 of the flexible spline gear 20 are radially clear of the splines 26 of the annular spline gear 24, on the minor axis of the wave generator 12.

The splines 26 on the annular spline gear 24 are of corresponding configuration to the splines 22 on the flexible spline gear 20, fewer splines 22,26 being provided on the flexible spline gear 20 than on the annular spline gear 24.

Upon rotation of the output shaft 14, the wave generator 12 is driven around, so that the point at which the flexible spline gear 20 meshes with the annular spline gear 24 moves around the annular spline gear 24. Because of the difference in the number of splines 22 and 26, engagement between splines 22 and 26, as the point of contact moves around the annular spline gear 24, will cause the flexible spine gear 20 to move in the opposite direction, relative to the annular spline gear 24.

For example, as illustrated in figures 2a to 2d, as the wave generator 12 rotates clockwise; when the wave generator has moved through $90^0$ as illustrated in figure 2b, the flexible spline gear 20 will have moved one quarter of the difference in the number of splines 22,26 on the flexible spline gear 20 and annular spline gear 24, in the anticlockwise direction. For example if the number of splines 26 on the annular spline gear 24 is 102 and the number of splines 22 on the flexible spline gear is 100, the flexible spline gear 20 will have moved one half of a spline anticlockwise, relative to the annular spline gear 24. Similarly as indicated in figure 2c, after $180^0$ of rotation of the wave generator 12, the flexible spline gear 20 will have moved one spline anticlockwise, relative to the annular spline gear 24; and as illustrated in figure 2d, after $360^0$ of rotation of the wave generator 12, the flexible spline gear 20 will have moved two splines anticlockwise, relative to the annular spline gear 24.

The harmonic drive 10 described above will consequently give a drive ratio

$$i = \frac{-n}{N}$$

where; $n$ = the difference in the number of

splines 22 and 26; and

$N$ = the number of splines 22 on the flexible spline gear 20.

In the example given above the drive ratio will consequently be -50:1, the negative value signifying that the drive is reversed. That is for 50 revolutions of the electric motor 16 in the clockwise direction, the flexible spline gear 20 will rotate 1 revolution in the anticlockwise direction.

As illustrated in figure 3 a contactless electric motor 16 is mounted within a cylindrical motor housing 32. A radially outwardly directed flange formation 34 at one end of the motor housing 32 is adapted to be secured by suitable means, for example by bolting, to for example a gearbox housing.

An output shaft 14 of the electric motor 16 extends coaxially of the motor housing towards the other end 36 thereof. A shift drum 40 is mounted on the motor housing 32 by means of rolling bearings 46.

An elliptical wave generator 12 is mounted on the output shaft 14, intermediate of the motor 16 and a closed end 44 of shift drum 40. A flexible roller bearing 18 is mounted on the wave generator 12 and a flexible spline gear 20 is mounted on the roller bearing 18. The flexible spline gear 20 is cup shaped, having an flexible annular portion 50 with axial splines 22 on its outer periphery, the annular portion 50 being mounted on the roller bearing 18, and a hub formation 52 which is secured to the closed end 44 of shift drum 40 by bolting or in like manner. A flexible cylindrical web portion 54 extends coaxially of the output shaft 14 and interconnects the annular portion 50 and hub formation 52 of the flexible spline gear 20.

A fixed annular spline gear 24 is formed integrally of the motor housing 32 concentrically of the wave generator 12 and the annular portion 50 of the flexible spline gear 20 mounted thereon. Alternatively the annular spine gear 24 may be secured to the motor housing in suitable manner. The annular spline gear 24 has splines 26 on its inner periphery.

With the electric motor shift drum actuator illustrated in figure 3, upon energisation of the electric motor 16, rotation of the output shaft 14 will drive the flexible spline gear 20 and shift drum 40 attached thereto in the opposite direction, the drive ratio depending on the difference in the number of splines 22,26 on the flexible spline gear 20 and fixed annular spline gear 24, being typically from -40:1 to -60:1.

In the double shift drum actuator illustrated in figure 4, first and second shift drums 200, 202 are rotatably mounted coaxially of one another on a shaft 204. The shaft 204 is mounted at one end in a spigot formation 206, provided in the gearbox housing 208, the other end of the shaft 204 being secured to a clutch housing 210, by means of nuts 212 and 214. The outer ends of shift drums 200, 202 are closed and are mounted on the shaft 204 by means of sealed rolling bearings 216. The inner ends of shift drums 200, 202 are mounted by rolling bearings 220 on an annular member 218 which is secured non-rotatably, centrally of the shaft 204. Seals 222 are provided between an internal diameter of the shift drums 200, 202 and an external diameter of the annular member 218.

Permanent magnet electric motors 230 are mounted on the shaft 204, the motors 230 being located internally of the shift drums 200, 202, coaxially and adjacent the closed outer ends thereof. The motors 230 comprise an annular stator 232 which is non-rotatably mounted on the shaft 204 and a rotor 234, rotatably mounted on the stator 232 by sealed rolling bearings 236. Elliptical

wave generators 238 are secured to the inner ends of each of the rotors 234 for rotation therewith.

A flexible spline gear 240 is mounted coaxially of each of the electric motors 230, between a rolling bearing 242 mounted on the outer periphery of the wave generator 238 and the internal diameter of the annular member 218. The outer periphery of the flexible spline gear 240 and the internal diameter of the annular member 218 are provided with splines which mesh on the major axis of the wave generator 238. The flexible spline gear 240 has fewer splines than the annular member 218.

The flexible spline gear 240 has a flexible web portion 244 which extends coaxially of the electric motor 230 , towards the closed end of shift drum 200, 202 and terminates in a hub formation 246. The hub formation 246 is defined by a radially inwardly directed flange formation 248 and a reduced diameter cylindrical portion 250 extending from the inner periphery of the flange formation 248 towards the closed end of shift drum 200, 202. An elastomeric bush 252 is mounted under compression, between the external diameter of the cylindrical portion 250 of the hub formation 246 and the internal diameter of the shift drum 200, 202, to drivingly connect the flexible spline gear 240 to the shift drum 200, 202 with axial and radial compliance.

An axial groove 254 is provided in the shaft 204 which may serve as a conduit for the electrical connections to the motors 230 and also as a key to prevent rotation of the shaft 204, annular member 218 and stators 232.

Position sensors 256 are provided on each of the shift drums 200, 202 for measuring the angular movement of the shift drums 200,202.

With the actuator described with reference to figure 4, when the electric motors 230 are energised, rotation of wave generators 238 will cause the point at which the splines on the flexible spline gear 240 and the annular member 218 mesh, to move around. Because of the difference in the number of splines of the flexible spline gear 240 and the annular member 218, this will cause the flexible spline gear 240 to rotate, driving the shift drum 200, 202.

The double shift drum assemblies described with reference to figure 4 is particularly suitable for twin clutch transmission systems of the type disclosed in co-pending UK Patent Applications GB 0028310 and GB 0103312, for example, shift drum 200 may be arranged to control shifts from R - $1^{st}$ – $3^{rd}$ – $5^{th}$ – R in association with one clutch and shift drum 202 may be arranged to control shifts from $2^{nd}$ – $4^{th}$ – $6^{th}$ – $2^{nd}$ in association with the other clutch.

Various modifications may be made without departing from the invention. For example while in the above embodiment elliptical wave generators are used, multi-lobe wave generators may be used so that the splines on the flexible spline gear engage the splines on the annular spline gear at more than two locations. This will not alter the drive ratio of the harmonic drive but will increase its torque transfer capability.

The patent claims submitted with the application are proposed formulations without prejudice to the achievement of further patent protection. The applicant reserves the right to submit claims for further combinations of characteristics, previously only disclosed in the description and/or drawings.

References back used in sub-claims refer to the further development of the subject of the main claim by the characteristics of the respective sub-claim; they are not to be understood as a waiver with regard to achieving independent item protection for the combination of characteristics in the related sub-claims.

Since the subject of the sub-claims can form separate and independent inventions with reference to the prior art on the priority date, the applicant reserves the right to make them the subject of independent claims or of division declarations. Furthermore, they may also contain independent inventions which demonstrate a design which is independent of one of the objects of the preceding sub-claims.

The embodiments are not to be considered a restriction of the invention. Rather, a wide range of amendments and modifications is possible within the scope of the current disclosure, especially those variations, elements and combinations and/or materials which, for example, the expert can learn by combining individual ones together with those in the general description and embodiments in addition to characteristics and/or elements or process stages described in the claims and contained in the drawings with the aim of solving a task thus leading to a new object or new process stages or sequences of process stages via combinable characteristics, even where they concern manufacturing, testing and work processes.

## CLAIMS

1. An electric motor actuator for control of a gear selector mechanism of a motor vehicle; including a mounting member by which the actuator may be mounted with respect to a support member, a shift drum mounted for rotation relative to the mounting member, an electric motor mounted coaxially inside the shift drum, the electric motor having a stator mounted non-rotatably with respect to the mounting member and a rotor, the rotor being drivingly connected to the shift drum for rotation thereof by means of a harmonic drive, the harmonic drive comprising a wave generator mounted on the rotor for rotation therewith, an annular spline gear non-rotatably mounted with respect to the mounting member concentrically of the wave generator and a flexible spline gear located between the wave generator and the annular spline gear, the flexible spline gear being drivingly connected to the shift drum, the flexible spline gear having fewer splines than the annular spline gear and the wave generator being shaped to cause the splines of the flexible spline gear to mesh with the splines of the annular spline gear at angularly spaced locations, the splines of the flexible spline gear being clear of the splines of the annular spline gear, intermediate of said locations.

2. An electric motor actuator according to claim 1 in which the drive mechanism has a drive ratio of from -40:1 to -60:1.

3. An electric motor actuator according to claim 1 or 2 in which the wave generator is of elliptical configuration, the flexible spline gear meshing with the annular spline gear at diametrically opposed locations on the major axis of the wave generator.

4. An electric motor actuator according to any one of claims 1 to 3 in which the flexible spline gear is cup shaped, having an annular portion with splines on its outer periphery, a hub formation and a flexible cylindrical web portion interconnecting the annular portion to the hub formation, the flexible gear being secured to the shift drum by means of the hub formation.

5. An electric motor actuator according to claim 4 in which the hub formation is secured to the shift drum by means of bolts or similar fastening means.

6. An electric motor actuator according to claim 4 in which the hub formation is secured to the shift drum in compliant manner.

7. An electric motor actuator according to claim 6 in which the hub formation is secured to the shift drum by means of a resilient bush, the resilient bush being mounted, under compression, between opposed circumferential surfaces of the hub formation and the shift drum.

8. An electric motor actuator according to any one of the preceding claims in which the electric motor is mounted inside a cylindrical motor housing, the cylindrical housing defining the annular spline gear, the shift drum being rotatably mounted on an external diameter of the cylindrical housing.

9. An electric motor actuator according to any one of claims 1 to 7 in which two electric motor shift drum assemblies are mounted coaxially of one another on a central shaft.

10. An electric motor actuator according to claim 9 in which an axial recess is provided in the central shaft.

11. An electric motor actuator according to claim 9 or 10 in which a stator of the motor is secured to the central shaft, a rotor being rotatably mounted radially outwardly of the stator.

12. An electric motor actuator according to any one of the preceding claims in which the shift drum/motor assembly is adapted to be located within a gearbox housing.

13. An electric motor actuator substantially as described herein with reference to and as shown in figures 1 to 4 of the accompanying drawings.

INVESTOR IN PEOPLE

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| **Application No:** | GB 0117563.7 | **Examiner:** | Mike Mckinney |
| **Claims searched:** | 1 to 13 | **Date of search:** | 7 November 2001 |

# Patents Act 1977
# Search Report under Section 17

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): F2D (DDA, DDD, DDE).

Int Cl (Ed.7): B25J 9/10; F16H 49/00, 55/08, 61/32, 61/34, 63/16, 63/18.

Other: ONLINE: WPI; EPODOC; JAPIO.

**Documents considered to be relevant:**

| Category | Identity of document and relevant passage | | Relevant to claims |
|---|---|---|---|
| Y | GB 2311829 A | (LUK) referred to on page 1. | 1, 3 to 9, 11 and 12. |
| Y | GB 2308874 A | (LUK) referred to on page 1. | 1, 3 to 9, 11 and 12. |
| Y | EP 0990819 A1 | (TEIJIN) see fig 1. | 1 to 9, 11 and 12. |
| Y | EP 0514829 A2 | (HARMONIC DRIVE SYSTEMS) see figs 1 and 2. | 1, 3 to 9, 11 and 12. |
| Y | US 6050155 | (TORTORA) see fig 1. | 1, 3 to 9, 11 and 12. |
| Y | US 4044274 | (OHM) see figs 1 and 2. | 1, 3 to 9, 11 and 12. |

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|---|---|---|---|
| X | Document indicating lack of novelty or inventive step | A | Document indicating technological background and/or state of the art. |
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